sMDT muon chambers
WBS 6.6.X.5

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U.S. ATLAS HL-LHC Upgrade NSF Conceptual Design Review

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sMDT experts

- Reinhard Schwienhorst, WBS 6.6.5.5
  - Associate Professor, Michigan State University
  - L3 manager for Phase 1 upgrade project: L1 Calorimeter trigger fiber plant

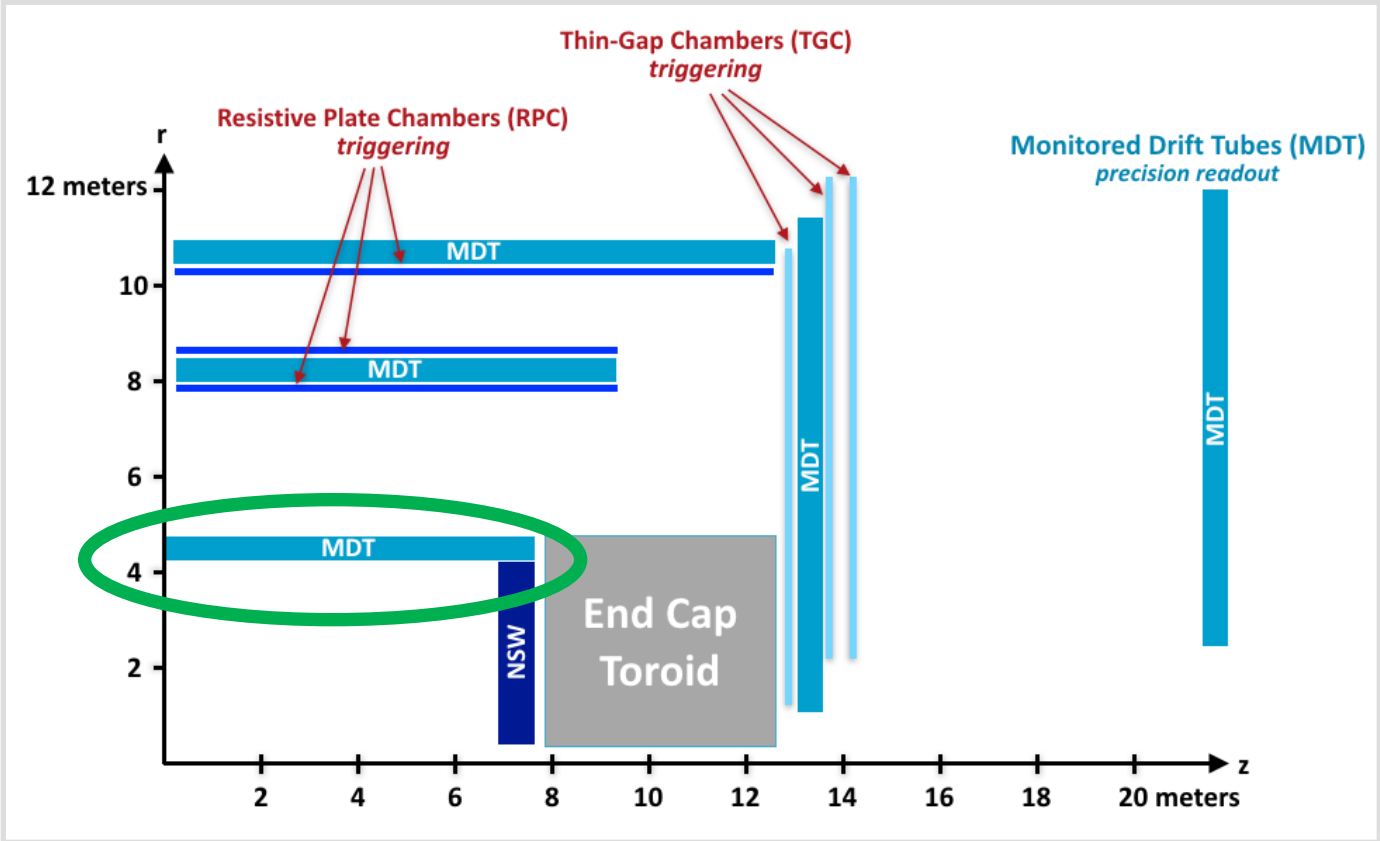
- Bing Zhou, 6.6.3.5
  - Professor, University of Michigan
  - The US ATLAS project leader for the current ATLAS MDT detector construction, commissioning and operations
  - The U of M project leader for design and construction of 32,000 tubes and 80 largest MDT chambers for the current ATLAS Muon Spectrometer

Institutes

- Michigan State University, WBS 6.6.5.5
  - Experienced electronics engineers
  - Experience in large construction projects
    - Tile calorimeter modules for ATLAS
    - Fibers for Nova neutrino experiment
    - Many others
- University of Michigan, 6.6.3.5
  - Long experience in muon detection
  - Room, granite table, infrastructure in place from MDT construction

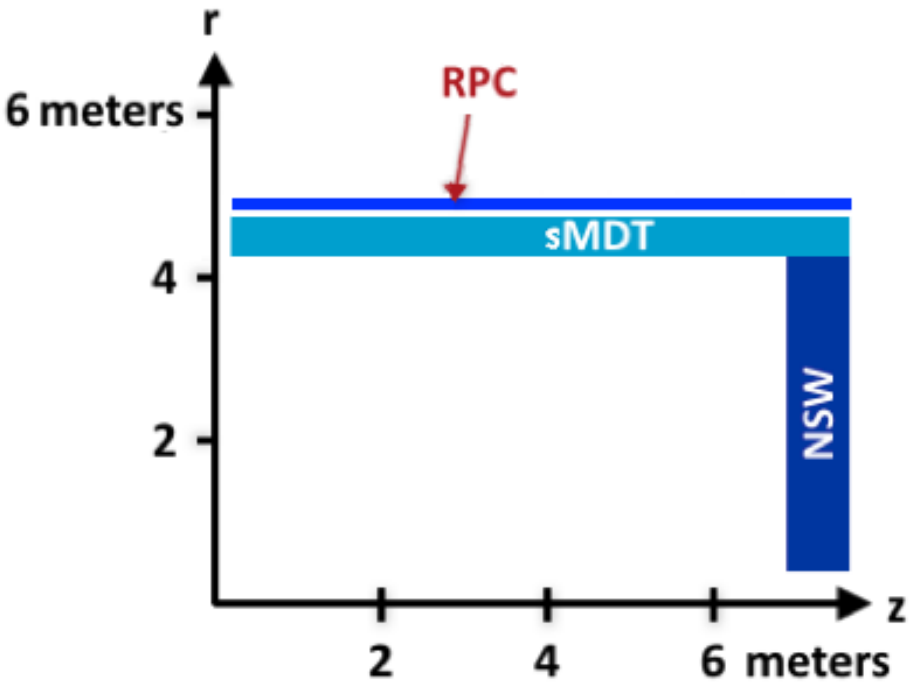
Introduction

- Replace monitored drift tubes (MDT) chambers in inner barrel of muon spectrometer with small-MDT and RPC
  - allow for 3 station MDT trigger to improve trigger p_T resolution
  - increase barrel trigger efficiency from 65% to 95%
- As part of improvements to muon trigger
  - Allow single-muon triggers at 20 GeV
  - Allow di-muon triggers at 10 GeV



sMDTs

- BIS MDT chambers are replaced by sMDT
- BIS 7-8 sMDT chambers will be installed in Phase-1
- BIS 1-6 sMDT chambers for Phase-2



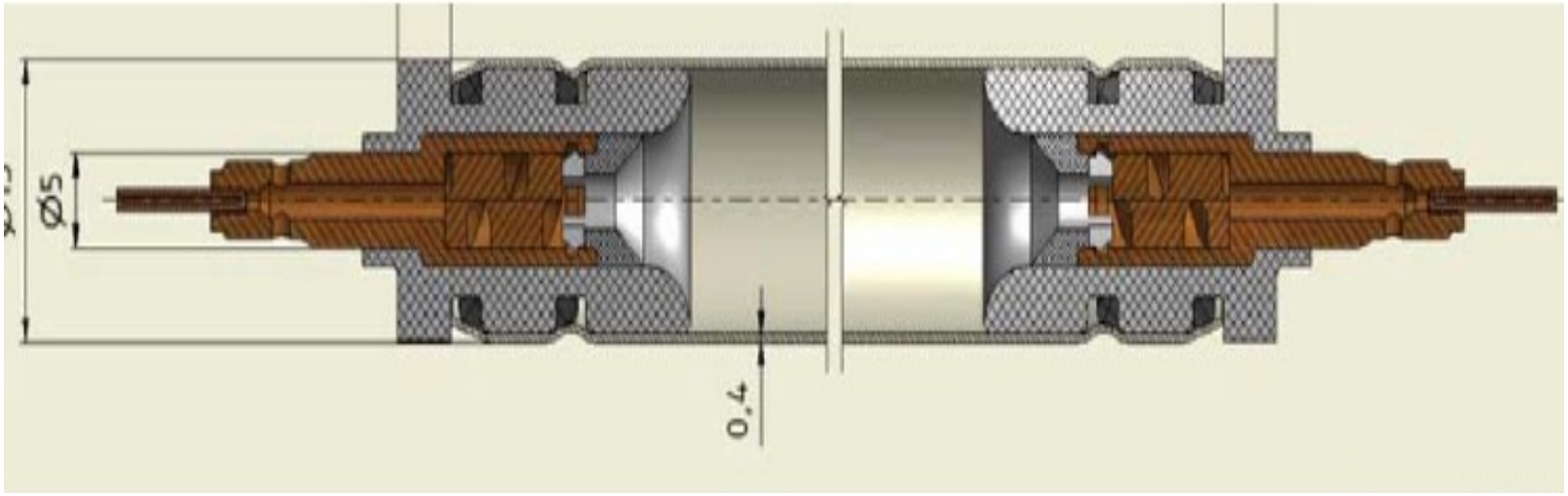
ATLAS sMDT upgrade

- Total: 48,000 tubes in 96 chambers
  - Half built at MPI in Munich, Germany with help from Protvino, Russia
  - Half built in US
- WBS 6.6.5.5: tube construction
  - In a clean room in HEP area at Michigan State University
  - By MSU HEP engineers and technicians
  - 25,000 tubes, incl. 5% overage
- WBS 6.6.3.5: Tubes assembled into chambers
  - In existing facilities at University of Michigan
  - By U of M HEP engineers and technicians
  - 48 chambers assembled and tested
- Close cooperation and coordination between the two institutes

WBS 6.6.5.5 – sMDT tubes

- Fabrication and assembly and testing of 25,000 sMDT tubes
  - Granite table for assembly
  - Automatic wiring station
  - Wire tension, tube leak and dark current test stations
- Tube production from April 2020 to Sept 2022
  - 4.75 FTE total
  - Shipping tubes to University of Michigan

sMDT tubes

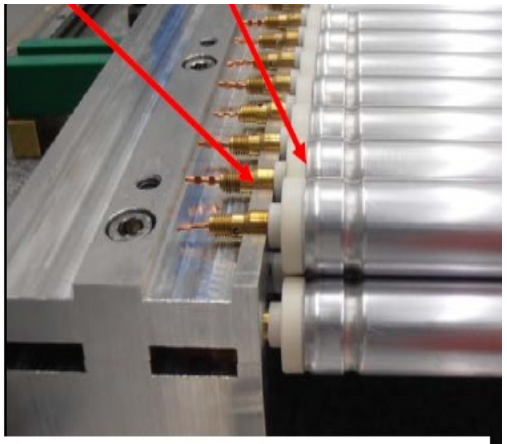


- Each tube 1.5 cm diameter, 1.67 m length
- Thin-wall (0.4mm) aluminum tube, wire 50 micron diameter, 2 precision end-plus, two precision wire-locator (twisters), 4 radiation-hard o-rings, two signal pins, and two signal caps
  - Purchasing through CERN in cooperation with MPI and Protvino

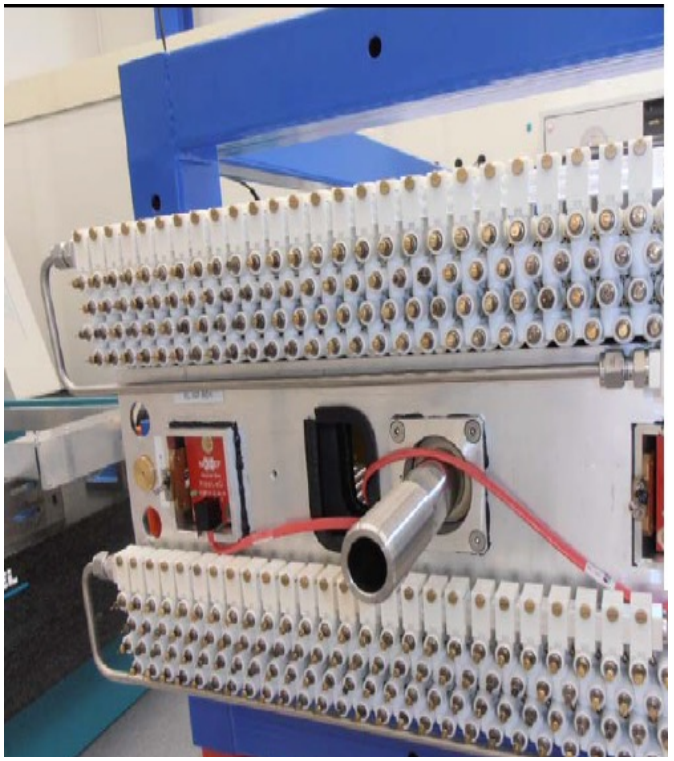
WBS 6.6.3.5

- Assembly and testing of 48 sMDT chambers
  - Chamber assembly precision jigging on granite table
  - Precision spacer assembly station
  - Gas assembly and test station and electronics (HV and RO) test station
  - Design of the mechanical structure for chamber mounting and integration with RPC as well as for alignment device installation mounts.
- Chamber production from July 2020 to December 2022
  - 9 FTE total
  - Ship chambers to CERN
- Installation and commissioning at CERN

sMDT chambers



Drift tube and sense wire positioning using external reference surface of endplugs



- Build the precision spacer frame
- Glue two multi-layer tubes to the space frame
- Mount the alignment sensors and install gas and HV/RO systems
- Test stations for tube location precision, gas manifold, HV, and electronics

Development

- Pre-construction is required in FY 2019
- MSU:
  - Set up clean room
  - Set up table and tooling
- University of Michigan:
  - Room and table already in place
  - Set up tooling
- Both institutions:
  - Set up testing stations
  - Fabricate model-0 tubes
  - Assemble and test model-0 chamber

Budget estimation

- Material estimate based on existing purchases at MPI Munich
- Engineering and technician estimate based on experience with MDT construction at University of Michigan and at MPI Munich

Risk

- Raw materials purchasing through CERN using CHF – Exchange rate fluctuations – Purchase tubes/end-plugs and so on in US?
- A lot of R&D was carried out when building the current muon MDT chambers to find qualified company who can provide high quality (tube wall thickness uniformity better than 10%, straightness better than1%, and well defined the tube clean procedure. We tested tubes from five different companies (including one from US) worldwide and selected one from Switzerland. The same situation for end-plugs and wire locator (twister), wire-pin and O-ring.
- Identifying US companies for these specialized precision, clean tubes, end-plus (radiation hard material, no out-gassing, no cracks under tube crimping pressure) would require intensive R&D, which would cost a lot more time and funds

Closing Remarks

- sMDT construction is rquired to enable Phase-2 muon trigger upgrades
- 25,000 tubes to be constructed at MSU
- Assembled into 48 chambers at U of M

Additional Material

Motivation and Scope of Building sMDT

- In order to keep high trigger efficiency (>90%) for Muon Spectrometer, an inner layer RPC detector must be added to Barrel Inner layer of the Muon Spectrometer
- To fit the RPC into the existing small space, MDT chambers must be replaced by small-tube MDTs for BIS chambers
- **The scope of the task**
  - total **48,000** drift tubes (diameter=1.5 cm, and length = 1.67m)
  - Assembled tubes into **96** sMDT chambers
  - US will build half of the system (i.e. 24,000 tubes, and 48 chambers) by MSU (for tubes) and UM (for chambers)
  - We will be in close collaboration with MPI and Protvino (Russian group) for the sMDT construction project

Tube pre-construction M&S and Manpower

Tube production tooling cost estimation			Cost	Comment -- need one year	
1) Wiring table (12 feet x 4 feet)			3000	Shipping from UM	
2) clean flowbox (2)			24,000	purchase	for wiring table
3) mechanical tube crimping device (2)			4,000	purchase	
4) Wire pin crimping tool (2)			4,000	purchase	
5) Auto-wiring tension system			5,000	build	
6) Tension test station			3,000	build	
7) Leak detector			22,000	purchase	
8) dark current test station			10,000	build	
9) Mech structures on wiring table			15,000	build	
10) gas system for leak test (flow meters...)			10,000	build	
11) module 0 tubes and parts (650 tubes)			12,000	construction	
12) other M&S (cealn cloth, shoe, and pads)			8,000	purchase	
Total tooling M&S cost			120000		
Manpower to build and test the tube assembly					
Mech engineer (1 FTE, Shooltz)		167400	Mech design and set up of the tooling		
Elec. Engineer (0.5 FTE)		82620	write software for auto wiring, test stations		
Mech. Tech. (1 FTE)		134850	Assist to build the wiring stations, Mod 0 tubes,		
Manpow for tooling		384870			
construct of 25000 tubes (with spares)			on average build and test 50 tubes per day.		
Materials for tube assembly					
Al tubes	25000 tubes (8/tube)		200,000		
Wire	1000/km		41,666		
end-plug	50000 (7.2/unit)		360000		
other M&S for clean room			10,000		
			611,666		
Manpower	Two FTE each year for 27 month				
Mech Tech (Nila)		1	90500	built tubes	69615.38
Mech Tech		1.25	113125	test tubes	
IDC/year			62218.75	55%	
Salary, bnefit, IDC/year			265843.8		
For 27 month (2.25 year)			598148.4	1,209,814	
Total cost for tube tooling and construction			1,714,684		

Tube construction M&S and Manpower

Chamber pre-construction cost

Chamber tooling		(Constrution tooling, one year, build/test Mod 0, 3 month, including review)					
Set up assebly room and tables			1 month		10,000	temp./humidity control system	
Design and produce the chamber assembly jigging			3 month		40,000	design and machining (2 sets)	
Design and build the gluing machine, test			2 month		100,000	purchase/build	
Install the tooling on granite table, and measurement tool			1 month		10,000	machining	
Precision measurement tooling and test/software			1 month		50,000	Purchase	
Design and construct the chamber handle carts			2 month		10,000	build	
Design and construct the gas maniford			1 month		10,000		
design the HV test electronics boards and set up test stations			2 month		10,000		
design and construct the gas test stations			2 month		5,000	Leak detector will need to be manteined	
design and construct the cosmic ray test station			3 month		10,000		
design the shipping boxes and protocal			1 month		5,000		
Design and produce spacer frame (mod 0)			1 month		10,000		
Design and produce gas manifold, parts (mod 0)			3 month		5,000		
Design and build the gas connection parts clean bath			2 weeks		3,000		
Design and build FC (Mod)			1 month		5,000		
Build Mod 0 (with clean room M&S, glue, mixing…)					5,000		
Gluing		2 weeks		Tooling cost	288,000		
Precision test		2 weeks					
gas connection		2 weeks					
FC connection	8 layer	1 week					
Test		1 month					
Manpower		15 month	(1.25 year)				
Mech Eng (1 FTE)		161280					
Electric Eng (1 FTE)		161280					
Mech Tech (1 FTE)		120960					
manpower for tooling		443520					

Chamber Construction M&S and Labor

Chamber construction			**27 month**					
Manpower		cost/year				**M&S**		
Mech tech	1.0 FTE	101606.4				Gas connectors		85000
Mech. Eng	0.5 FTE	67737.6				Spacer/support		48000
computing prof.	0.5 FTE	59270.4				FC		24000
Eng student	2.0 FTE	129024				Gas distribution		19000
construciton manpower		357638	**804686**			Alignment parts		18500
						Transport tools		24000
						HV/RO distribution		212500
								431000

Details of the Base Estimate (Explanation of the Work)

This BOE covers the production of 50% of the sMDT chambers needed for the Muon Spectrometer phase II upgrade to add the Level-1 trigger device in the barrel inner station of the Muon Spectrometer. The effort includes fabrication of assembly and test stations for tube and chamber constructions, purchasing precision tubes and end-plugs and other components needed for construction tasks, making total 24000 tubes and assemble these tubes into 48 chambers, shipping of the complete sMDT chambers to CERN in early 2023 for integration with RPC and pre-commissioning prior to installation in ATLAS pit in 2024.

Labor for pre-production (tooling and model-0)

1) **Pre-production**: build the **tube** and **chamber** assembly and test stations and produce module-0 to certify the precision and procedure for construction tasks.
   a. Will need labor for tube pre-construction: 1.0 FTE mechanical engineer, 1.0 FTE mechanical technician and 0.5 FTE electrical engineer for 12 months in 2019 – to build the automatic wiring station, and the wire tension, tube leak and dark current test stations
   b. Will need labor for chamber pre-construction: 1.0 FTE mechanical engineer, 1.0 FTE mechanical technician and 1.0 FTE electrical engineer for 15 months in 2019 – 2020 – to build the automatic gluing machine, the chamber assembly precision jigging on granite table, the precision spacer assembly station, the gas assembly and test station, and electronics (HV and RO) test station. In addition, design the mechanical structure for chamber mounting and integration with RPC as well as for alignment device installation mounts.

2) Labor sMDT construction

a. Construction and test total 25000 tubes (with 5% spares) starting from April, 2020 and finish by Sept. 2022 requesting total 4.75 FTE mechanical technician support. Assuming on average constructing and test 50 tubes each day. The task will need 1.0 FTE for tube assembly and 1.0 FTE for tube tests (wire tension, leak and dark current). Faculty member will need to provide supervision for construction and testing.

b. Construction and test total 48 sMDT chambers in 27 months starting from July 2020 and finish by Dec. 2022. All the sMDT need to be shipped to CERN by the end of 2022. Assuming on average constructing and test one chamber (gluing 8 layers of tubes and a precision spacer frame) every two weeks. In addition, the different types of spacer frames need to be designed and fabricated, as well as the gas system and HV and RO distribution boards, and the FC must be installed on chamber and perform gas leak and HV tests for each chamber. The task will need 0.5 FTE mechanical engineer, 0.5 FTE electric engineer, 2.0 FTE mechanical technician and 1.0 FTE engineer student for 27 months. Faculty member will need to provide supervision for construction and testing.

The needed labor FTEs are based on experience with the MDT tube and chamber constructions for Run 1 muon detector at the University of Michigan, as well as the sMDT construction experience at MPI (Germany) for muon detector Phase I upgrade project.

Summary Labor for sMDT construction: (total 13.75 FTE)

Total 4.75 FTE of Mechanical Technician for tube assembly and test

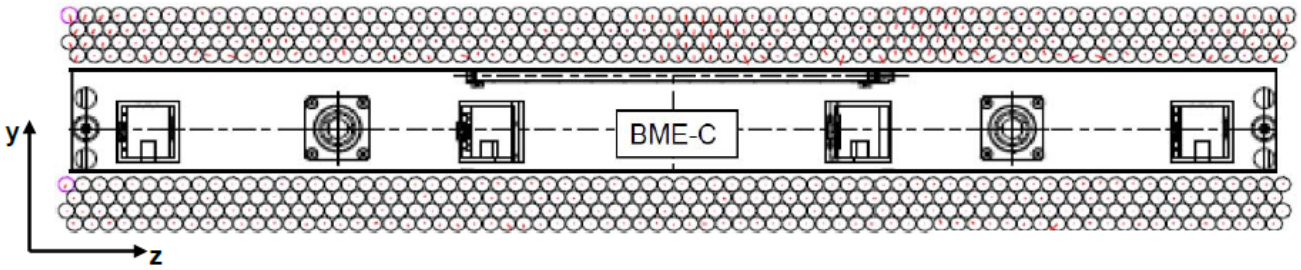
Total 9.0 FTE (1.125 M.E., 1.125 E.E., 4.5 M. Tech. and 2.25 E. student)

Engineering support

- Mechanical engineer at University of Michigan is Curtis Weaverdyck and electric engineer is Jon Ameel, they are experienced engineers with MDT construction and test. They will be available and re-direct their effort on sMDT project in 2018.
- Mechanical engineer at Michigan State University is Dean Shooltz. He has experience in ATLAS tilecal electronics, but also in previous ATLAS and other construction projects

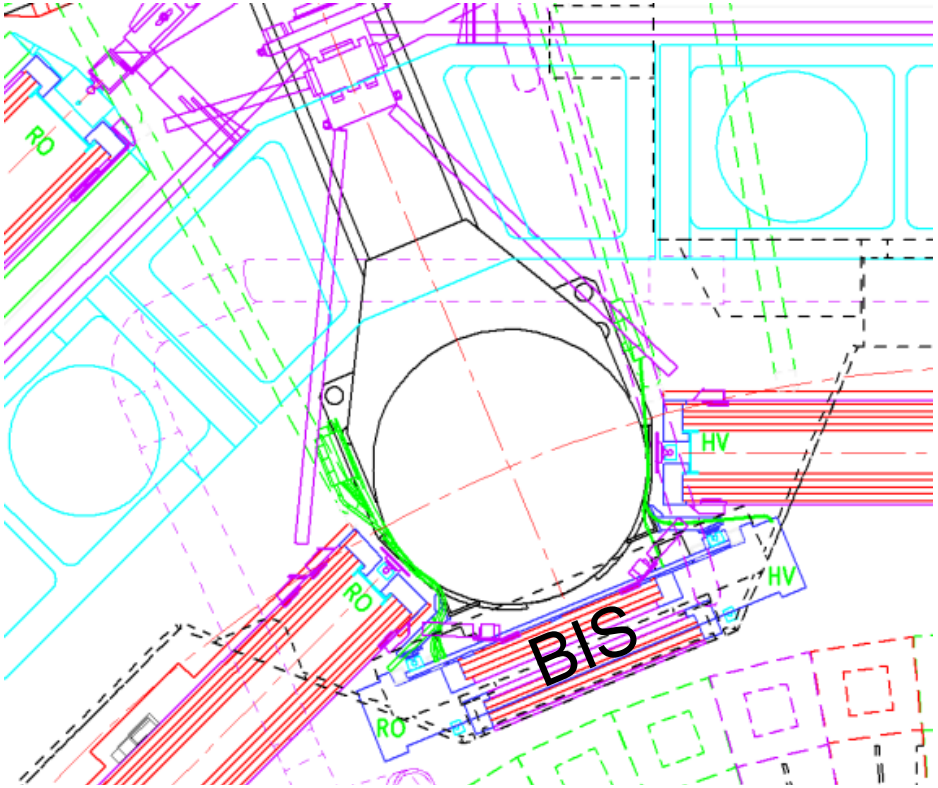
Mechanical precision

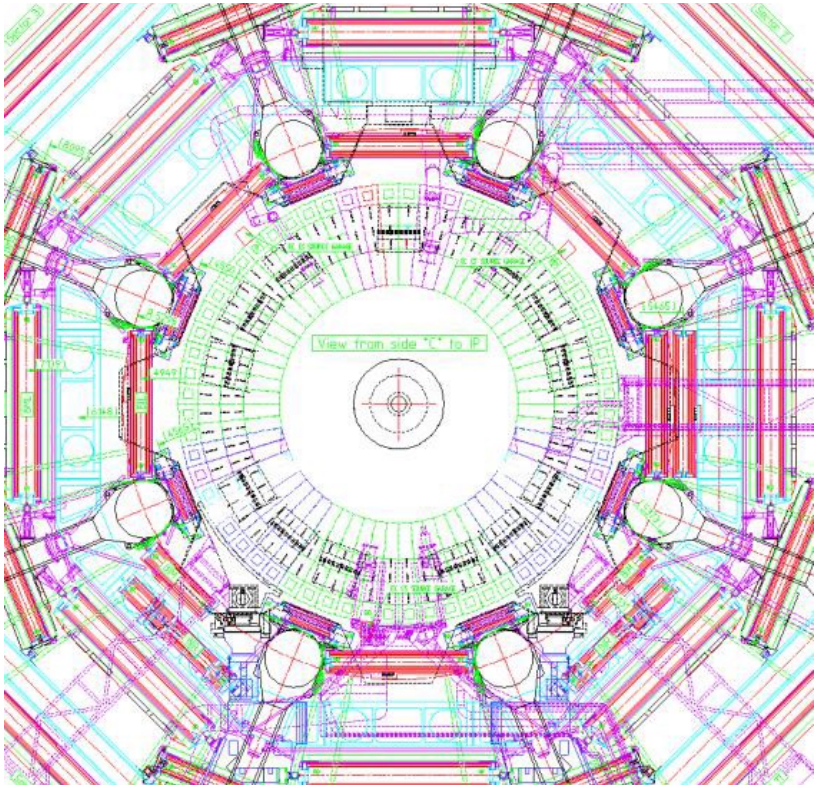
BME-A	RO side	HV side	Nominal from measurement of jigs
z-pitch [mm]	15.099 ± 0.0001	15.099 ± 0.0001	15.100
y-pitch [mm]	13.096 ± 0.001	13.086 ± 0.001	13.095 (RO) 13.085 (HV)
z-offset layers [mm]	7.553 ± 0.0001	7.551 ± 0.0001	7.550
z-distance ML [mm]	0.008 ± 0.001	0.014 ± 0.001	0
y-distance ML [mm]	135.339 ± 0.002	135.266 ± 0.002	135.345 (RO) 135.270 (HV)
RMS wire pos. z	7 µm	7 µm	20 µm
RMS wire pos. y	11 µm	8 µm	20 µm



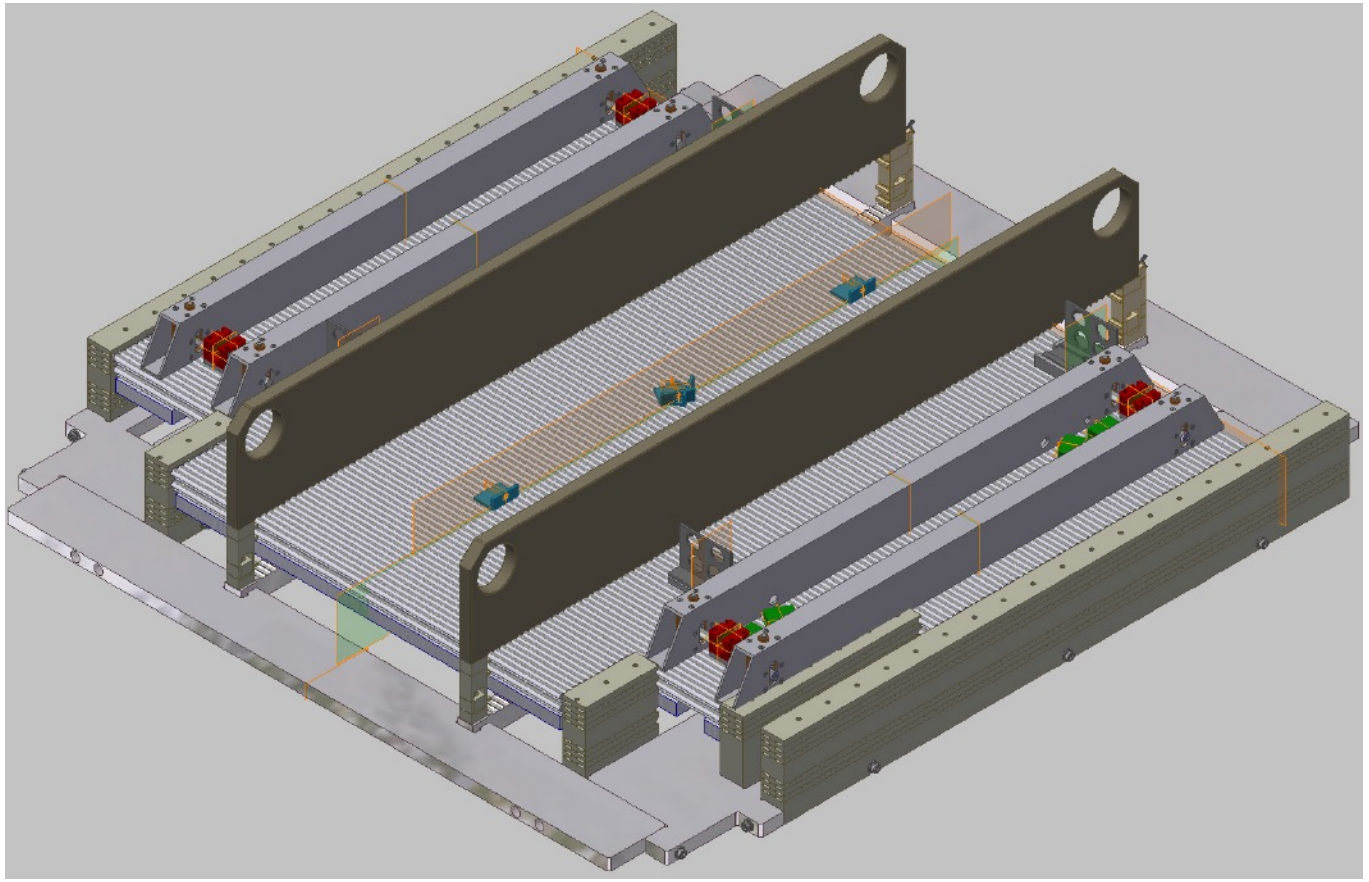
Excellent wire positioning accuracy and reproducibility from CMM measurement of endplugs immediately after construction.

MDT chambers in the current Barrel Muon Spectrometer
BIS is under the magnet coil



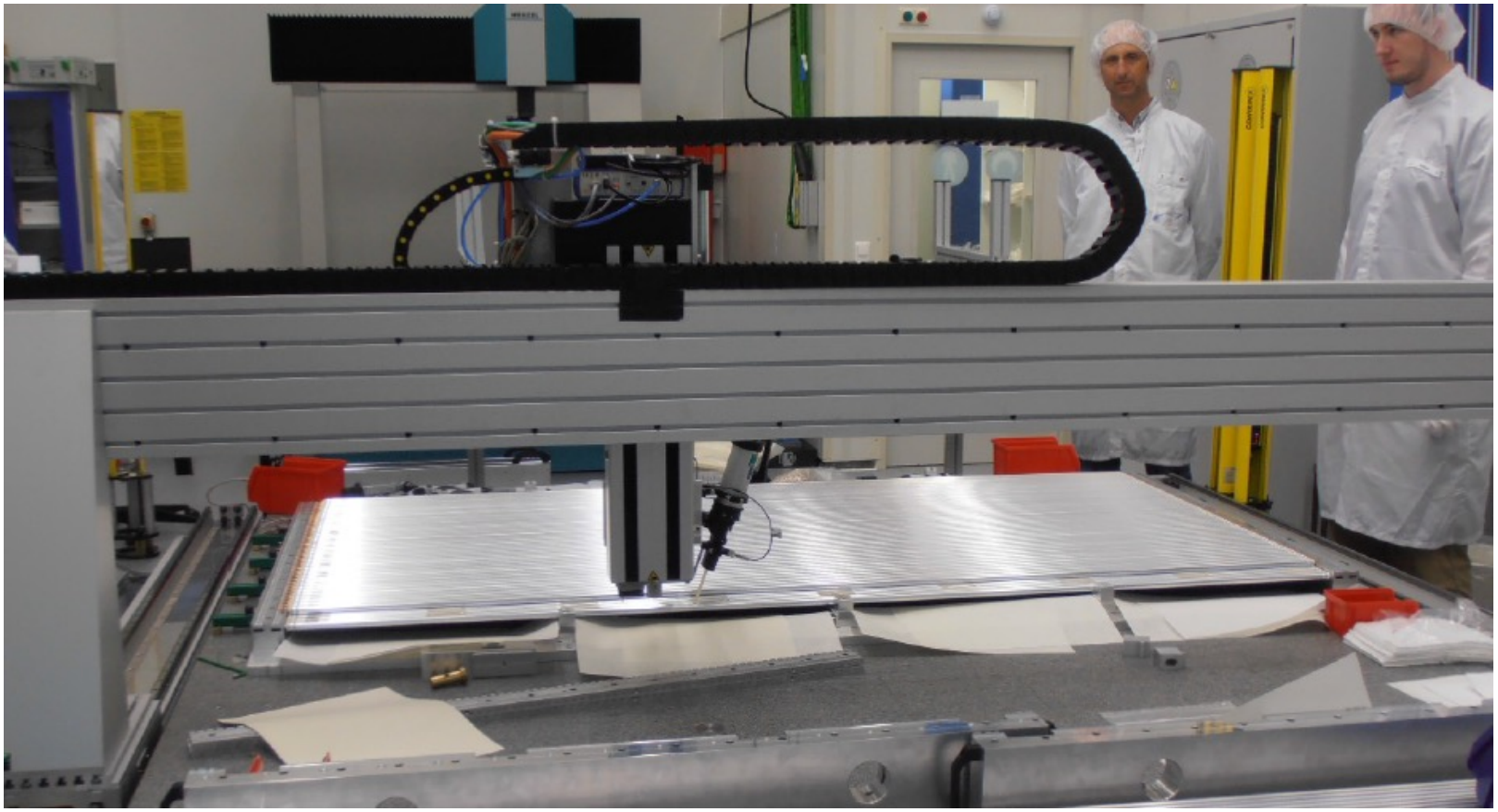


Need to build new sMDT Assembly Tooling

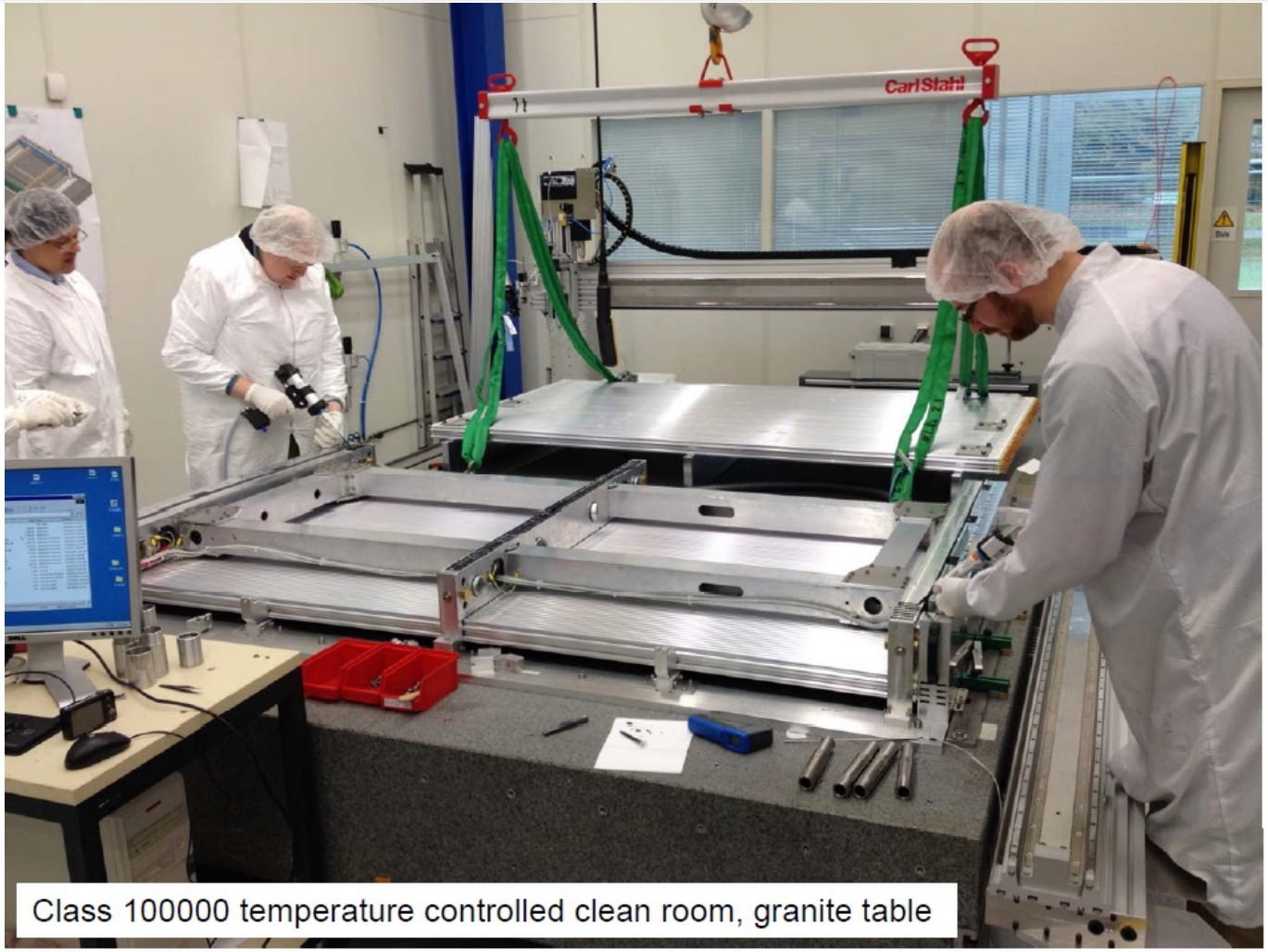


Construction of spacer frame

Automatic gluing machine

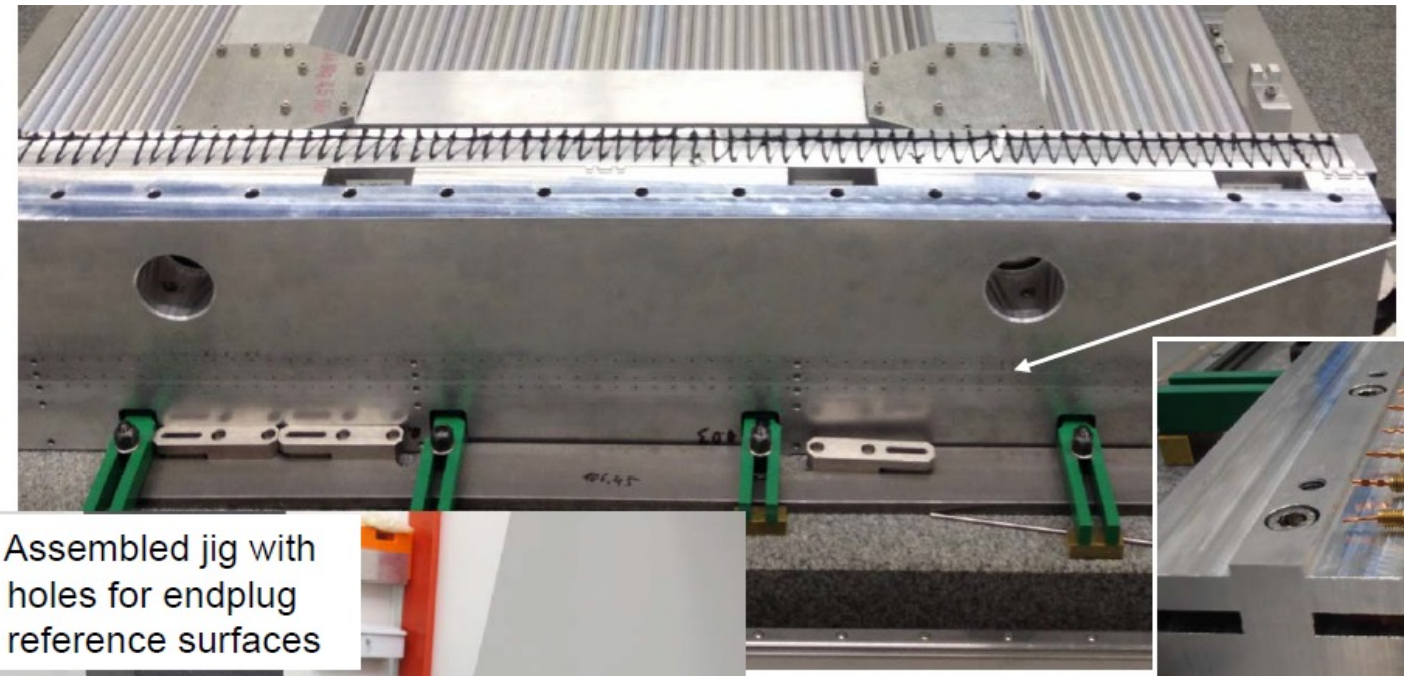


Chamber construction

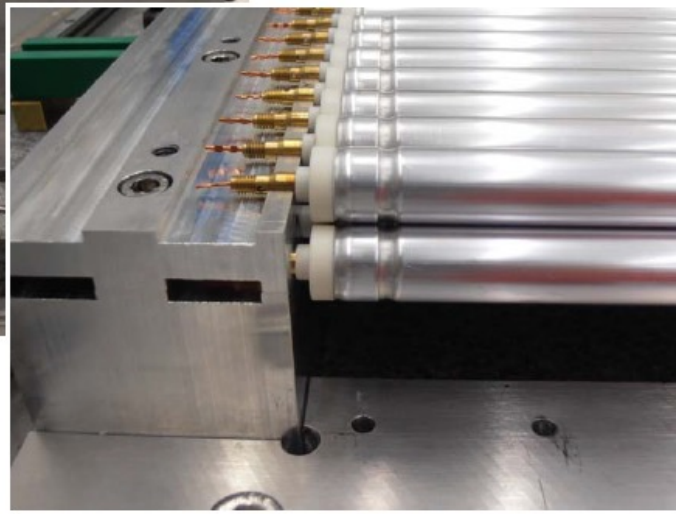


Class 100000 temperature controlled clean room, granite table

Chamber construction



Holes for ground pins screwed into the gaps between three adjacent tubes

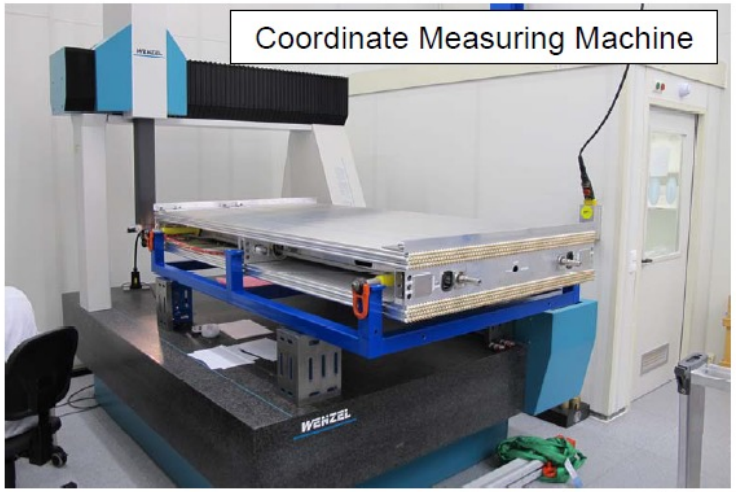


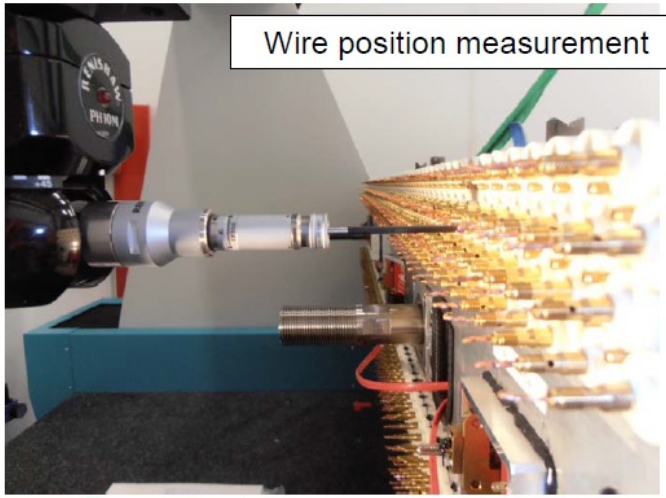
Assembled jig with holes for endplug reference surfaces

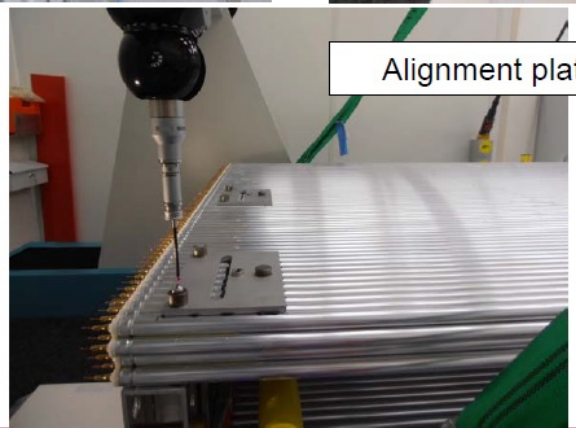
Chamber assembly:
stacking of tube and comb layers including spacer frame

⇒ glueing of a whole chamber within one working day

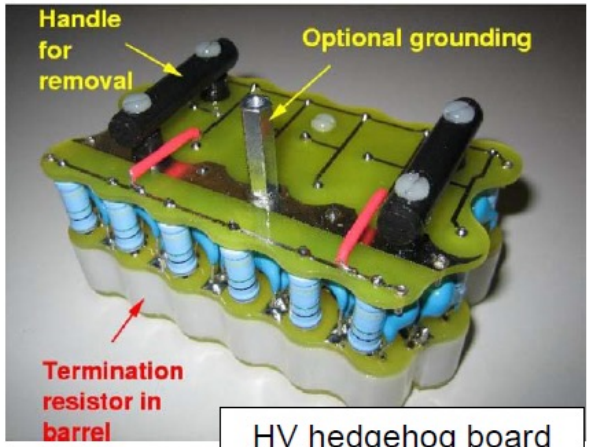
Optical QA/QC tests







HV and RO distribution boards

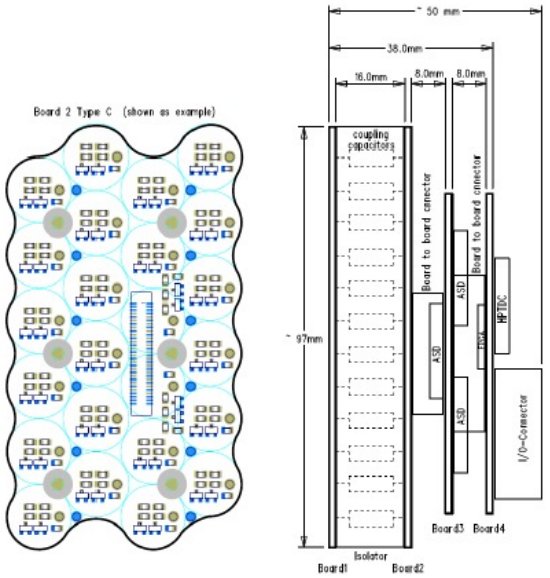


HV hedgehog board

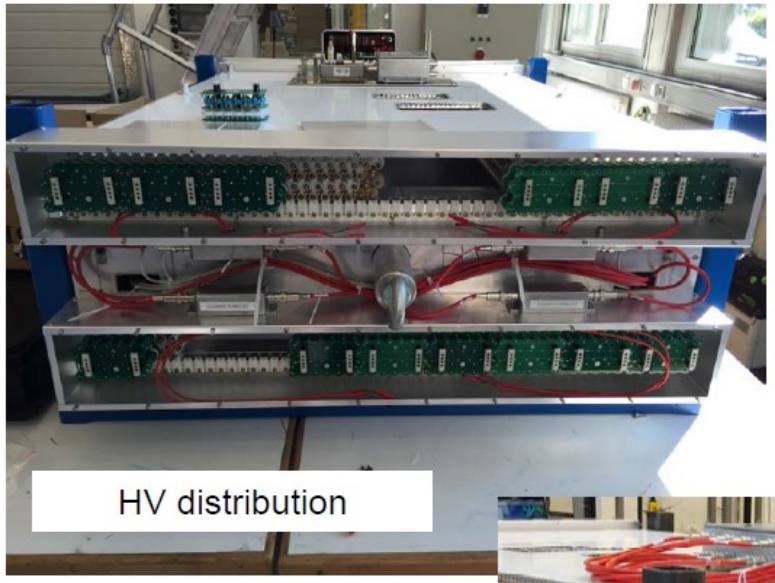

RO hedgehog and mezzanine board

sMDT HV and RO distribution boards and active readout boards (mezzanine cards) already designed and produced for BMG and BIS 7/8 chambers. Will be produced by MPI for BIS 1-6.

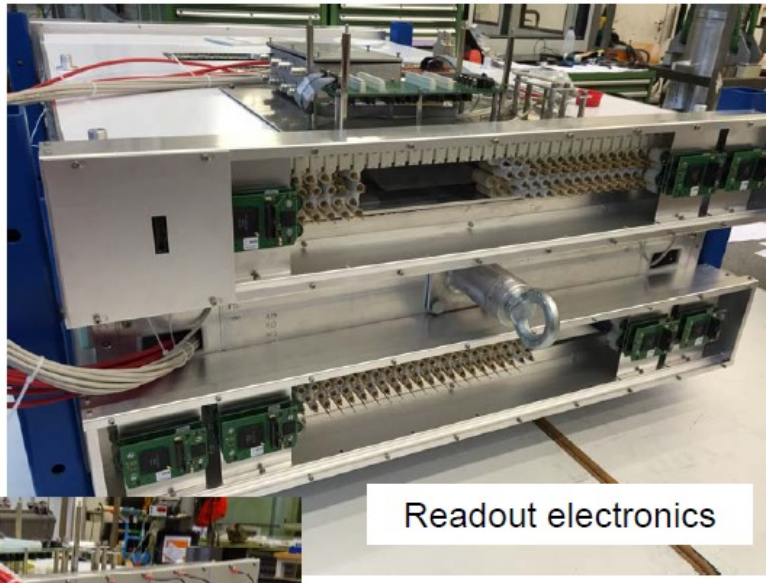
New ASD and TDC chips are under development which include MDT L0 trigger functionality.



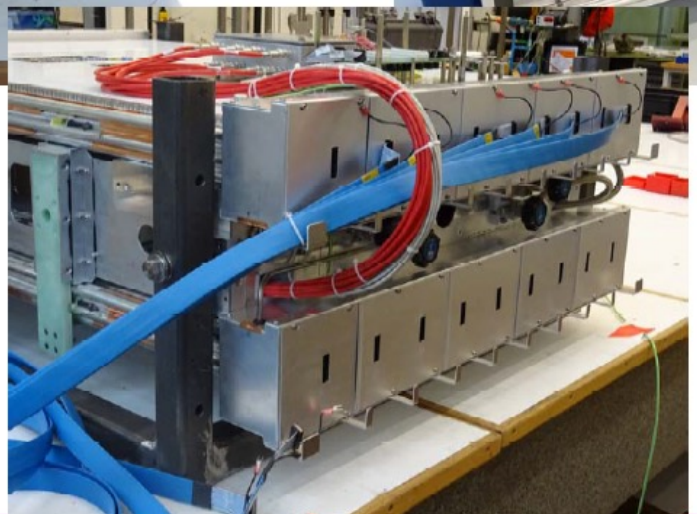
Gas system, Readout FE mounts



HV distribution



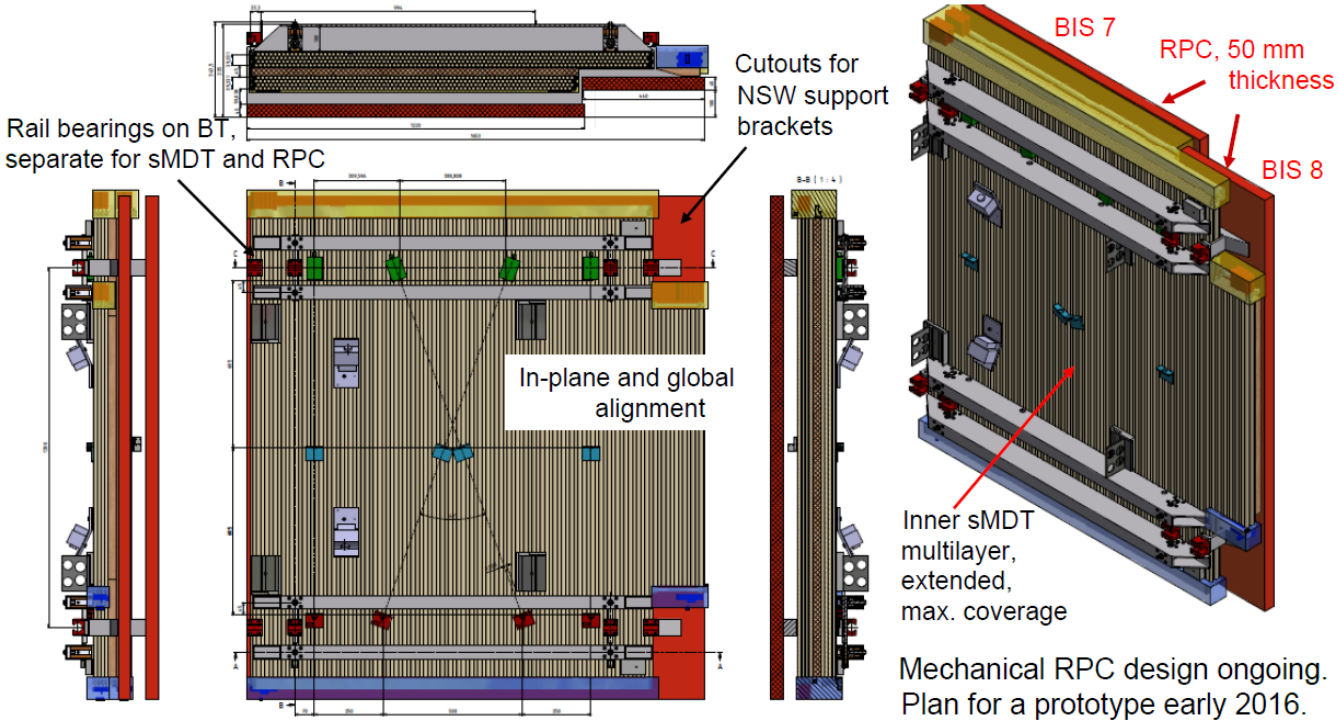
Readout electronics



Integration with RPC and Alignment system

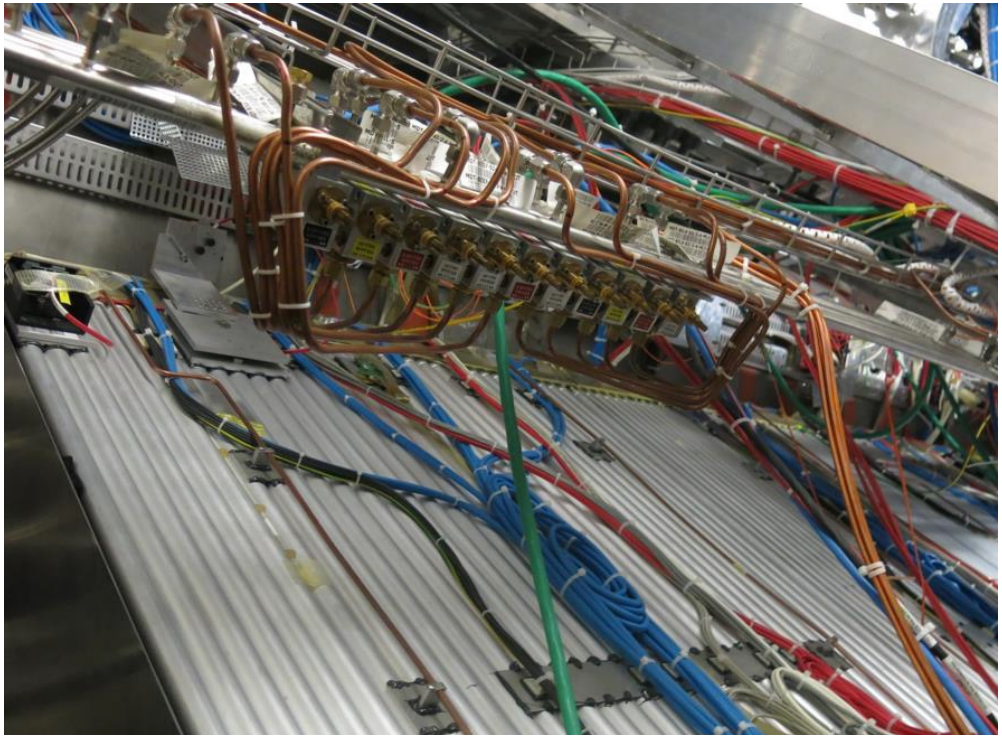
Integrated BIS 7/8 sMDT and RPC design with alignment connections to New Small Wheel.

sMDT design close to final. Model for Phase II BI layer upgrade.



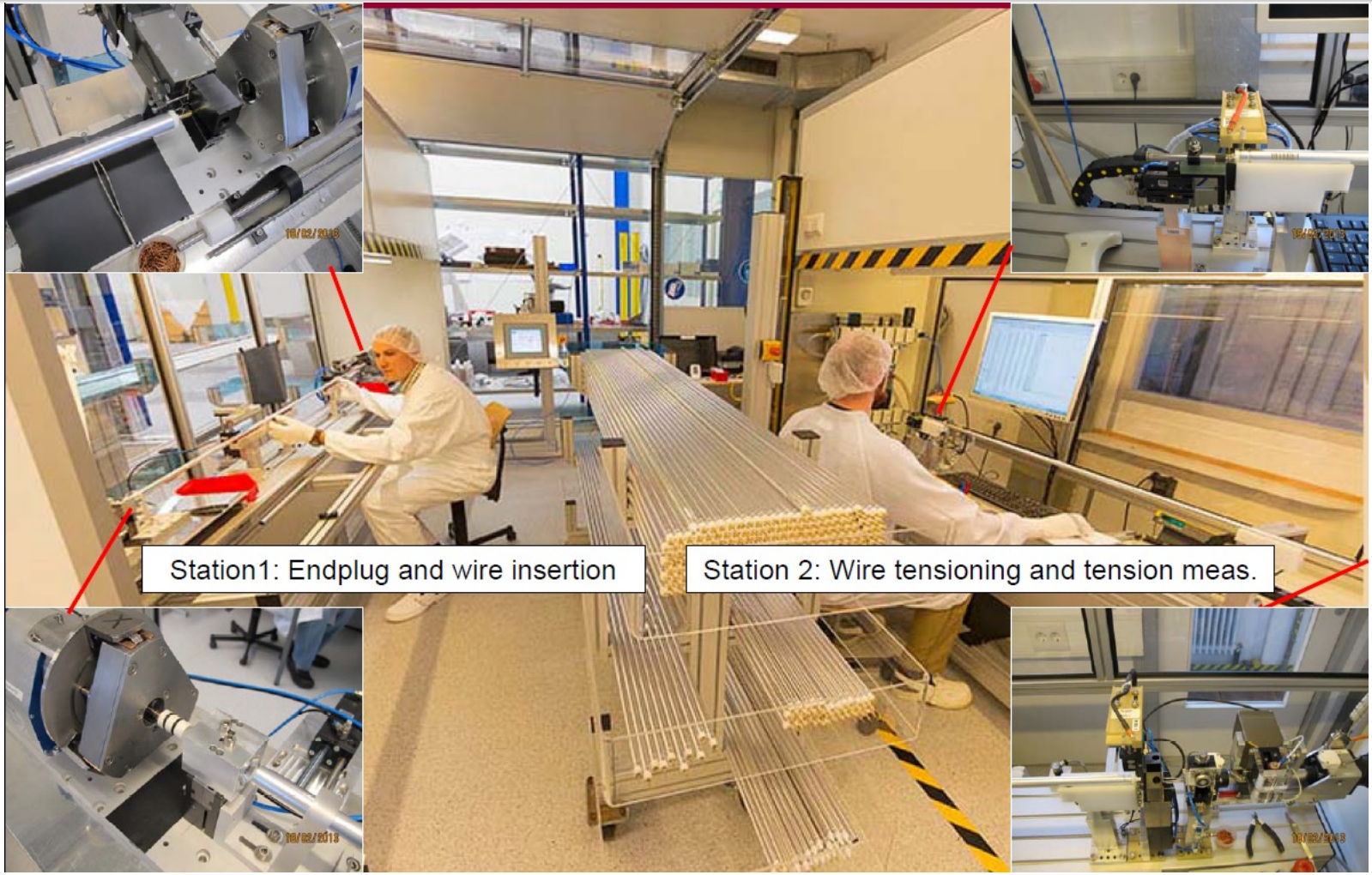
Mechanical RPC design ongoing.
Plan for a prototype early 2016.

Barrel MDT chambers in Muon Spectrometer



Engineering Design

Tuber construction facilities



1 Feeding of wire through tube and endplugs by clean air flow w/o touching the wire piece inside the tube

2 Automated insertion of endplugs into the tube

3 Automated mechanical swaging of the endplugs into tube with tool rotating the tube

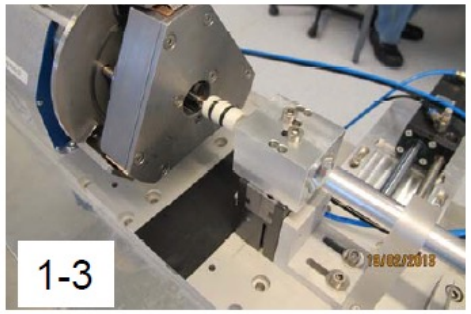
4 Automated crimping of the wire in copper crimp tubelet at one tube end

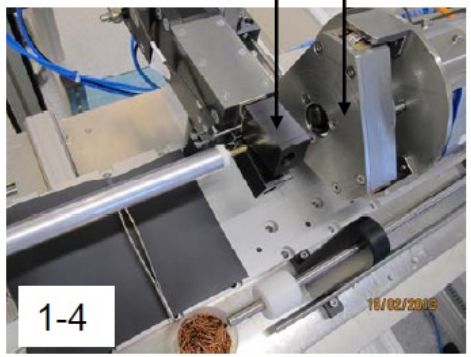
5 Automated wire tensioning and crimping at other end

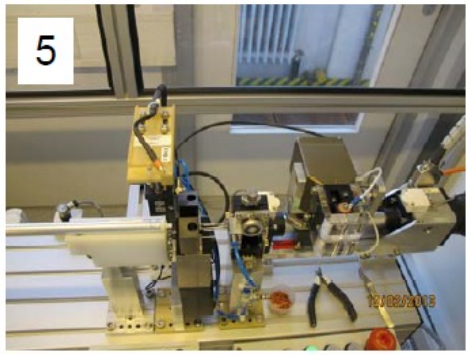
6 Automated wire tension (oscillation frequency) measurement

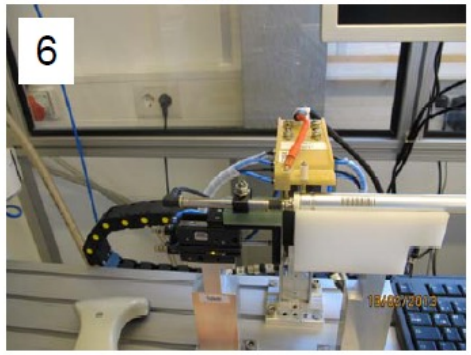
Drift tube production rate: 100 tubes/ day

by 2 technicians handling the tubes

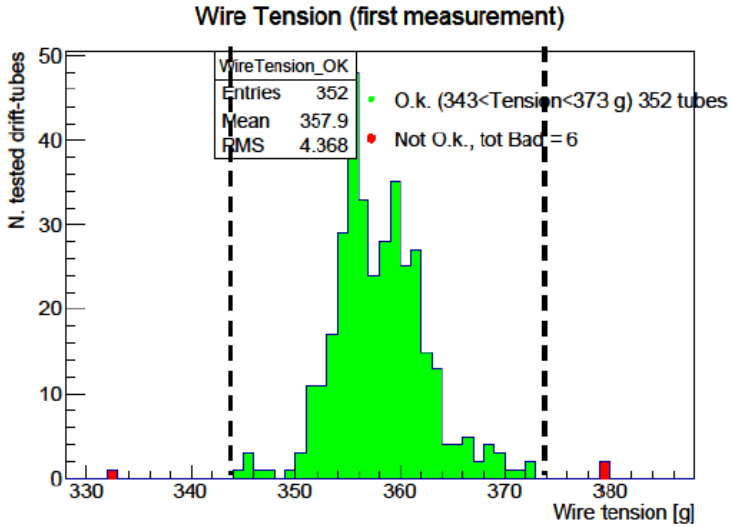


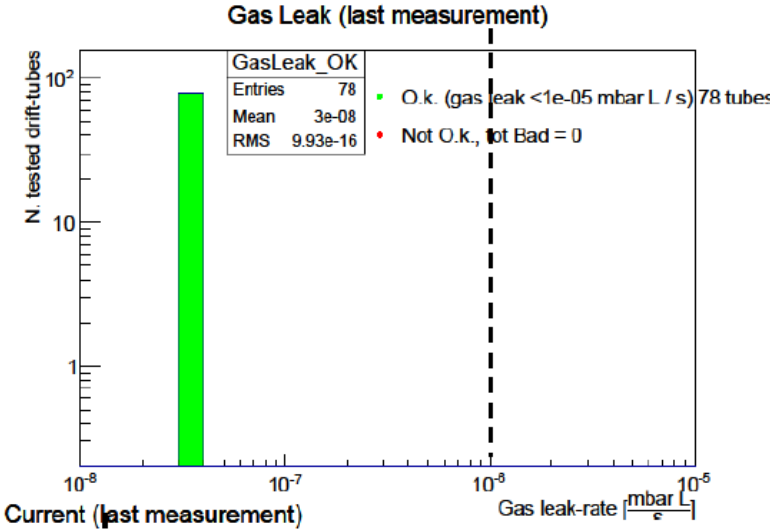


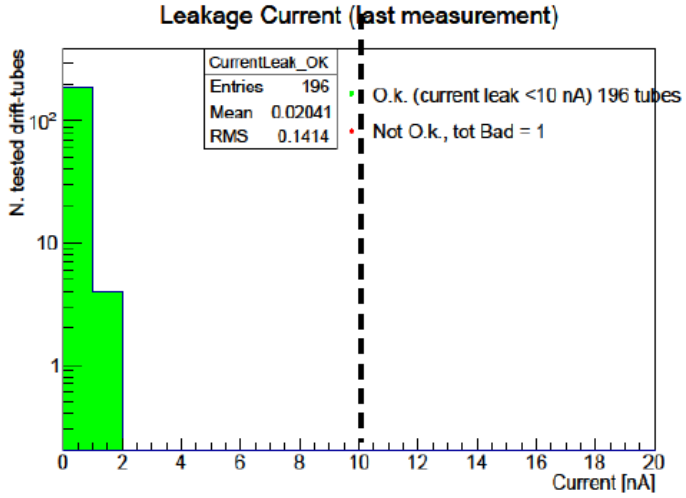




Automatised leakage current and gas leak rate measurement over night. Same quality control as for MDTs, except that there is no need for wire position measurement with new endplug design.







Experience at University of Michigan 2000-2003

Constructed 80 largest precision MDT Chambers

Constructed 32,000 long precision tubes